

Radiation Shielding Efficiency of Eco-Friendly Composite Materials Against Gamma and Neutron Radiation

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Abstract

The increasing development of nuclear usage in the fields of healthcare, energy, defence and aerospace necessitate efficient but/and sustainable radiation shielding applications. Conventional materials, e.g. lead and concrete, despite being effective, present a challenge to toxicity, weight and environmental hazards. In this paper, theoretical and recent progress on green composites which use natural fibers, waste polymers, and non-hazardous fillers such as bismuth oxide and Boron carbide have been investigated. It examines how gamma and neutron radiations interact with matter, and how to measure the shielding efficiency using mathematical representation- linear attenuation coefficient, half-value layer and macroscopic cross-section. The results confirm the possibility of sustainable composite materials as a part of the contemporary radiation protection field, as it is a much safer, lighter, and environmentally conscientious alternative. These new ideas could be used in new designs of materials to be used in variety of shielding applications.

Keywords: Radiation shielding, Eco-friendly composites, Gamma radiation, Neutron radiation, Natural fibre.

Introduction

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The trend in medical imaging and nuclear power generation as well as the use of radiology technology in aerospace and defence are reasons why there are more people using nuclear technology in diverse applications and activities all over the world and this has heightened the need to use radiation shielding technologies that are not only efficient but also eco-friendly. Although the heavy shielding materials composed of lead, steel, and concrete long found their application because of high density and attenuation capabilities of these materials, they have serious disadvantages. These are poisonous nature, weight, low recycling rate and significant environmental implication of production and disposal. Due to these concerns, studies have now become more focused on developing environmentally friendly composite materials which could otherwise give similar shielding effects and at the same time has lesser effects on the environment and health.

Such advance composites are developed by combining natural fibers (such as hemp, jute or flax), bio-based or recycled polymer matrices with non-toxic High-Z (such as bismuth oxide, or tungsten compounds) fillers and gamma-damping with neutron-absorbing additives like boron carbide or gadolinium oxide. The combination enables lighter, tailorable, and safer ways to develop shielding. In addition, they are recyclable or biodegradable to some extent thus being sustainable and efficient with their lifecycle. This type of material finds special use in those areas where weight, personal safety, and environmentally friendly design are particularly important- e.g. in personal protective gear, field diagnosis units and portable shielding applications to space vehicles or space operations or portable field equipment.

Literature Review

Demir et al. (2022) presented an all-inclusive review of the green materials to the radiation shielding material with focus on increasing interest of green materials to the traditional radiation shielding material. The purpose of their study was to investigate the potential use of natural fibers, agricultural waste and biodegradable polymers in the shielding composites formulation. The authors have emphasized that the novel non-materials would help to increase structural and radiation transmission characteristics of these composites, especially when used in the field of forestry and construction. They also discussed the issue of mechanical stability, moisture resistance, defining nanostructure fillers and hybrid design as a possible solution to it.

Akman et al. (2023) studied green composites of polymers developed in such a way that they are used to perform the roles of nuclear shielding. Contained in a volume on advanced composites, their work examined the combination of high-Z fillers, such as bismuth oxide and tungsten oxide, with polymer matrices, e.g. epoxy and polyethylene. The paper has shown that such composites have valuable properties such as weight saving and design flexibility in addition to their ability to substantially attenuate the gamma as well as the neutron radiations. Akman and other researchers highlighted the presence of hybridization and incorporation of boron-based compounds to boost neutron shielding power thus these composites are extremely flexible in their application in medical, aerospace and nuclear sectors.

Abdelgawad et al. (2023) concerned with the preparation of a clear glass material using rice straw ash as an aim to translucent against radiation (neutron and charged particle). The authors of the research used silica-rich agricultural waste as one of the basic raw materials and developed a glass composition with both optical transparency and pronounced radiation attenuation characteristics. In this research, the outcomes showed that the ready eco-glass possessed a relatively high potential to be applied in those places where both the visibility and the ability to protect the radiation is an issue like it is in the nuclear windows of observation and radiation-protective barriers in medical diagnostics.

Fundamentals of Radiation and Shielding Mechanisms

Radiation shielding is based on the knowledge of interaction between the gamma rays and neutrons with the matter. Gamma radiations, which are highly energetic photons, are interacted by three main ways namely the photo electric effect, Compton scattering, and the production of pairs. Photoelectric effect takes place with small energies and works most on materials that are rich in a high atom number such as lead and bismuth. Compton scattering prevails at middle-energy range (0.1 to 10 MeV) and the transfer of energy to electrons is partial and takes place in low- as well as High-Z mediums. At higher photon energies (greater than 1.022 MeV) higher energy photons undergo a process known as pair production, where the photon is converted into an electron-positron pair, helping to shield the high energy photons.

Gamma attenuation is an exponential law of absorption:

$$I = I_0 e^{-\mu x}$$

where μ is the linear attenuation coefficient, I is the transmitted intensity, I_0 is the initial intensity, and x is the thickness of the material. Comparing various materials is made easier by the mass attenuation coefficient μ/ρ , while the half-value layer (HVL), provided by:

$$\text{HVL} = \frac{\ln(2)}{\mu}$$

Specifies the thickness which decreases gamma intensity to half.

Neutron radiation, which consists of uncharged particles, interacts with the matter by elastic scattering, inelastic scattering and neutron capture. In elastic scattering, a collision of neutrons with light nuclei (such as hydrogen) results in energy which renders materials such as water, polyethylene and plant fibers as moderators. At the greater energy, there is inelastic scattering, which excites the heavy nuclei, which in turn emits gamma rays. The process of neutron capture occurs when a transmission of thermal neutrons is taken by such isotopes as the boron-10 or gadolinium-157, which frequently leads to secondary radiation.

Mathematical Evaluation of Radiation Shielding Efficiency

Mathematical models exist that define the manner in which radiation intensity diminishes in a material and this forms a basis of evaluation of radiation shielding performance. In the case of gamma radiation 9570m the most important parameter will be known as the linear attenuation coefficient (μ) indicating the reduction in radiation by a unit thickness. The simple formula of attenuation is:

$$I = I_0 e^{-\mu x}$$

Where I is the transmitted intensity I_0 is the incident intensity, μ is the linear attenuation coefficient (cm^{-1}), and x is the shield thickness (cm).

Another related quantity of interest is the Half-Value Layer (HVL) or the thickness required to decrease the gamma intensity by 50%. It is estimated to be calculated as:

$$HVL = \frac{\ln(2)}{\mu}$$

A lower HVL means better gamma shielding efficiency.

Conclusion

This research paper observes potential of environmental-friendly composites as viable substitutes to traditional shielding materials. The incorporation of natural fibers, bio-based polymers and the high-resultant, non-toxic additives make these materials effectively attenuate the gamma and neutron radiations and provide added advantages of less toxicity, weight, as well as flexibility of designs. Mathematical analyses enhance their applicability in the medical, nuclear, and the aerospace areas. They are also easy to manufacture and adapt to the complicated shapes and this adds to their practical significance. There is a need to research and innovate on the materials formulations to optimise the available radiation protection requirements as the world continues to demand sustainable radiation.

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